THE EFFECT OF TEMPERATURE-DEPENDENT VISCOSITY ON MANTLE CONVECTION: APPLICATIONS TOWARDS THE THARSIS RISE.

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The currently accepted model of mantle convection on Earth suggests that the pattern of convection in a spherical shell takes the form of subducting plates and upwelling, axi-symmetric plumes, defined as buoyant columns of hot mantle rising from the core-mantle boundary. Although the source of plumes remains somewhat controversial, it is generally accepted that a plume originates as instability at a thermal boundary layer in the mantle. As the plume rises, it develops a large mushroom-shaped head followed by a narrow tail less than a few hundred kilometers in diameter [1].

Surface features, such as the Tharsis and Elysium volcanic provinces, are the clearest topographical expressions of convection on Mars [2]. The long-wavelength areoid and topography highs associated with the Tharsis Rise are also attributed, in part, to convective flow [3]. These observations imply that thermal convection in the Martian mantle is very different from that of the Earth's. In particular, Mars may be dominated by one main, long-lived plume, as is indicated by the size and extent of the volcanism in the Tharsis region [4]. In our research we examine various parameters involved in mantle convection and relate the results to observations of magmatism on Mars, especially Tharsis.

Mantle convection is driven by a combination of many parameters. We have studied the effect of varying the Rayleigh number, rate of internal heating and temperature-dependent viscosity using a core-mantle thickness ratio appropriate for Mars (1525 km/3394 km). We varied the above parameters to determine their effect on Martian mantle convection by looking at resulting areoid and topography profiles over plumes in a spherical, axisymmetric mantle. For our convection modeling we use a finite element code [5] that takes advantage of the symmetrical shape of plumes using axisymmetry geometry. This reduces the three-dimensional problem to a two-dimensional computation.

For models with constant viscosity, an increase in Rayleigh number or rate of internal heating will result in a decrease in topography and the corresponding areoid with this relationship being well understood. We use a Rayleigh number of 10^6 which has been suggested to correspond to a middle-aged Martian mantle [2] and 40% internal heating in order to obtain steady-state solutions. However, the results of [6] and [7] indicate that constant viscosity calculations significantly over estimate the topography and areoid. Thus, we modify the above model by incorporating a temperature-dependent viscosity into the convection simulation. Plumes forming in a temperature-dependent viscosity fluid are reduced by a factor of two in comparison to plumes in a constant viscosity fluid [6].

We are using the observed topography and areoid as constraints on our convection calculations. However, in order to investigate the dynamical processes in the Martian mantle the component of topography and areoid due to crustal compensation must be removed. In examining the relationship between MOLA topography and areoid, expanded in spherical harmonics, we see a strong correlation beyond degree 4. Because it is believed that lower harmonics are influenced by dynamic support, we filter out spherical harmonic degrees greater than 4 to remove the isostatic component of topography and areoid. This is done, for example, by subtracting the isostatic areoid (i.e. [3]) from the observed areoid (i.e. [8]) and comparing the remaining component to our dynamic models.

For our temperature-dependent viscosity calculations, we use an Arrhenius form of the temperature-dependent part of the viscosity law:

$$\eta(\theta) = \eta_o \exp\left(\frac{E^*}{\theta + T_o}\right)\exp\left(-\frac{E^*}{1 + T_o}\right),$$

where η_o is pre-exponential viscosity, $\eta(\theta)$ is the effective viscosity, θ is the dimensionless temperature, and E^* is the activation energy divided by $R\Delta T$, where ΔT is the temperature scaling factor, and T_o is the temperature offset.

Although the study of temperature-dependent viscosity has been examined by others (i.e. [9], [6], [10]), our work uses a significantly greater number of elements than used in previous calculations. This becomes important in studying the variation of the rheology between elements. Our preliminary results show that as the activation energy increases, the topography, areoid and corresponding width of the anomaly over the plume increases (Figure 1). This is due to the increase of lateral variation in viscosity in the near-surface thermal boundary layer. However, at a dimensionless activation energy of about 1.8, the topography and areoid anomalies begin to stabilize. This is due to the increasing rigidity of the near-surface thermal boundary. In this case, the effect of lateral viscosity variation becomes less important than the increasing stiffness of the whole boundary layer. This becomes an important key to understanding convection and/or plume formation under the Tharsis rise because it is possible for lateral variations to exist in the near surface due to the crustal dichotomy.

Future work will include three-dimensional spherical calculations of the preliminary studies. This will allow us to fully incorporate the crustal dichotomy into our calculations so we can model the interaction between the mantle and crust.

References

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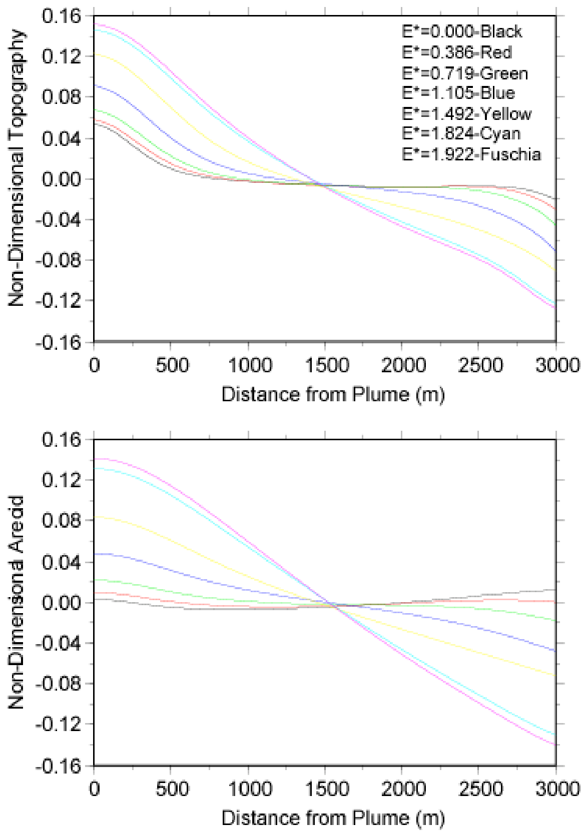

Figure 1: Areoid and topography profiles over plumes with temperature-dependent rheology.